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Whistlers observed at low latitude stations Bhopal and Jammu

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Abstract : The whistler data presented has been observed during nighttime of February-March 1998-99, though the occurrence is very small. The characteristics of whistlers are presented and the discussion indicates that whistlers recorded are strongly indicative of non-ducted propagation for low latitude nighttime whistlers observed at Bhopal (geomag. lat., 13° 47′ N) and Jammu (geomag. lat., 19°26′ N). To explain these results, it is proposed that whistlers recorded are the VLF waves radiated from the return stroke of the lightning discharge launched at the ionosphere with different initial wave normal angles. Such type of whistlers has never been reported from any of the low latitude ground stations so far.

Keywords : VLF emissions, whistler, electromagnetic field, magnetic field

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1. Introduction

The investigations of whistler waves were pioneering and heuristic in Space Physics. It is well known that lightning discharges are accompanied by the generation of electromagnetic waves in a wide frequency range [1-13]. The broadband very low frequency (VLF, 0.3-30 kHz) radiation from the lightning propagates in the Earth-Ionosphere cavity as impulsive signals (spherics) and in the dispersive plasma regions of the ionosphere and magnetosphere it propagates as tones of descending or rising frequency (whistlers) [14]. Since the pioneering work of Storey [15] who was the first to give a correct interpretation of whistler spectra in terms of magneto-ionic theory, the observation of whistlers has been continued over a 65 wide range of high to low latitudes [16]. Originally, whistlers were looked upon essentially as middle and high latitude phenomenon; but the pioneering work of Indian and Japanese Scientists during the last three decades have not only detected whistler traces at much lower latitude but have also established many of their morphological features. A wide variety of whistlers recorded during day and night times at low latitude ground stations, are markedly different from those recorded at middle and high latitudes [16-22].

It is now reasonably well established that whistler waves propagate in the ionosphere and magnetosphere in the different modes, namely ducted and non-ducted. The ducted propagation is characterised by their confinement to the field-aligned columns of enhanced or depleted ionisation [14, 23, 24] whereas the non-ducted propagation is characterised by simple propagation controlled by electron density and magnetic field gradients [25-27].

Although whistlers have been extensively observed at low latitude ground stations (see [18] for a review), relatively few cases have been reported of satellite observations [28, 29]. One

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of the principal conclusions of ground-based whistler studies at low latitude station is that while some of the whistlers observed on the ground propagated in ducts, a nonducted propagation path is needed to explain the properties of a large number of low latitude whistlers. This is primarily due to (i) the relatively high curvature of the low latitude field lines, which requires unreasonably large enhancements (~ 100%) in density to effectively guide the waves along the field lines, and (ii) the requirement of favourable ionospheric tilt at the duct entrance and exist.

Numerous studies of low latitude whistlers have been summarised by various workers [16-20]. It is shown that low latitude whistlers are characterised by a sharp occurrence peak in the day time and a broad small maximum in the post midnight period, on the basis of not only observational but also theoretical study. Night-time whistlers are observed maximum in the winter season over a wide time interval but generally peak in the early morning, and their dispersion is widely distributed.

In order to obtain further understanding of morphological properties of low latitude whistlers and of the associated plasma structure of the ionosphere and magnetosphere, we have carried out whistler measurements at both the ground-based stations of Jammu and Bhopal. This paper substantiates the preliminary results and diurnal and seasonal variations of the occurrence rate of ground whistlers observed at Jammu as well as Bhopal, and then we discuss the propagation mechanism of whistlers observed at Bhopal and Jammu.

2. Data interpretation

It is well known that at low latitudes, the whistler occurrence rate is low and sporadic. But once it occurs, its occurrence rate becomes comparable to that of mid-latitudes [30]. Similar behaviour has also been observed at our low latitude Indian Stations Bhopal and Jammu.

Using standard whistler observation equipments consisting of a T-type antenna 25m high, suitably amplified by a transistorised pre -and main amplifiers having band pass of 500 to 15,000 Hz, a magnetic and digital tape recorder, we conducted routine observation of whistlers at low latitude ground station Jammu, between December, 1996 to June, 2000 and at Bhopal, between December, 1999 to March 2000. The accumulated data on magnetic and digital tapes were analysed on a digital sonograph and Kay Elematrics Sonograph machine available at Physics Department of Banaras Hindu University, Varanasi, and Centre of Electronics Engineering Research Institute, CEERI Complex, NPL complex, New Delhi.

3. Dispersion characteristics

The results of the analysis showed a number of whistlers by different dispersions during night time. The frequency spectrograms of some of the whistlers with different dispersions out of large number of events are shown in Figures 1 and 2. The date and time of the observations of whistlers are mentioned at the top of figures. The sample records of night-time whistlers are shown in Figures 1 and 2, which are recorded on different dates. The night-time whistler activity was observed during quiet and disturbed days. Figure 1(a) shows a whistler duct with dispersion of about 12 $s^{1/2}$ recorded on March 26, 1998 at Jammu The $\sum Kp$ index corresponding to March 26, 1998 is 18 which is magnetically a disturbed day. Figure 1 (b) shows a whistler duct with dispersion of about 14 $s^{1/2}$ recorded on April 3, 1998 The $\sum Kp$ index corresponding to April 3, 1998 is 12, which is

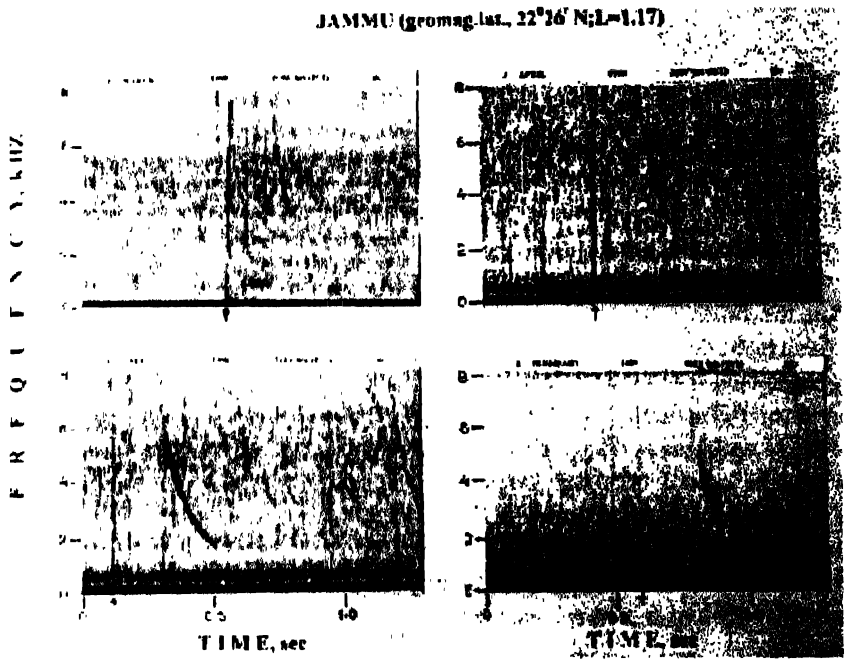

Figure 1. Frequency – time spectrograms of whistlers recorded at low latitude station Jammu

magnetically a quietest day. Figure 1 (c) shows a whistler duct with dispersion of about 16 $s^{1/2}$, recorded on April 8, 1998. The ΣKp index corresponding to April 8, 1998 is 12 which is magnetically a disturbed day. Figure 1 (d) and Figure 2 (a) show a whistler duct with dispersion of about 17 $s^{1/2}$, recorded on February 21, 1999. The ΣKp index corresponding to February 21, 1999 is 7 which is magnetically a quietest day. Figures 2 (b, c) show a whistler duct with dispersion of about 18 $s^{1/2}$, recorded on March 2, 1999. The ΣKp index corresponding the March 2, 1999 is 26, which is magnetically a disturbed day. Figure 2(d) shows a whistler duct with dispersion of about 22 $s^{1/2}$, recorded at our low latitude ground station Jammu on March 19, 1999. The ΣKp index corresponding to March 19, 1999 is 13 which is magnetically a disturbed day. A large number of whistlers have been observed on these days and the dispersion analysis of these whistlers shows a remarkably smooth increase in dispersion within the observation period.

Figure 3 shows a whistler duct with dispersion of about 3 $s^{1/2}$ and in Figure 4, the dispersion is 5 $s^{1/2}$ recorded on March 20, 1999 at low latitude ground station Bhopal. The ΣKp index corresponding to March 20, 1999 is 10, which is magnetically a quiet day.

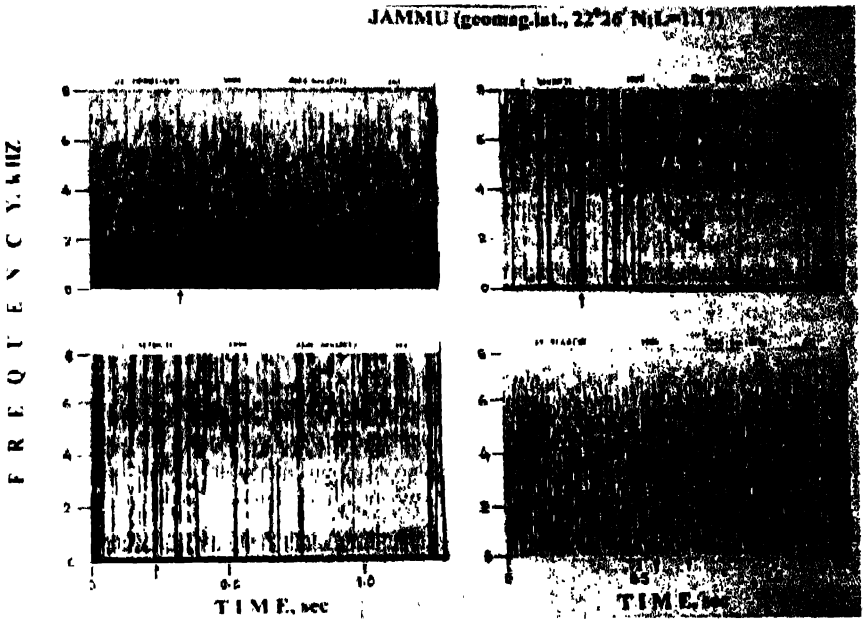

Figure 2. Frequency – Time spectrograms of whistlers recorded at low latitude station Jammu

4. Results and discussion

From the detailed spectral analysis of night-time whistler data recorded at Jammu, it is found that the measured dispersion values of all the recorded whistlers are found to be small lying in the range of ~ 3-20 $s^{1/2}$. We have not observed so far any traces of whistlers of high dispersion at our ground based stations Jammu and Bhopal. These whistlers are found to obey strictly the Eckersley's law (Dispersion being constant with frequency), thereby indicating that the whistlers had a quasi-longitudinal whistler-mode of propagation with a right-handed circular polarization. The normal dispersion values of whistlers observed at Jammu should be about 23 $s^{1/2}$ based on minimum critical

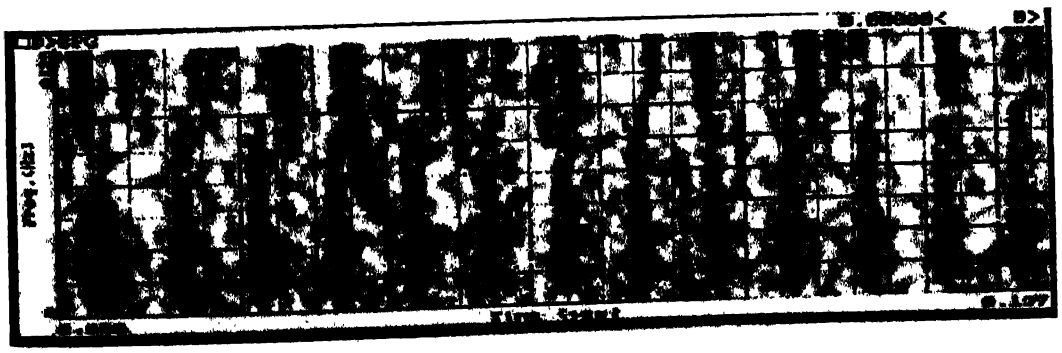

Figure 3. Frequency – time spectrograms of whistlers recorded at low latitude station Bhopal.

frequency of the F_2-layer and the electron number density at the equatorial height of the geomagnetic line of force corresponding to Jammu and from the regression line given by Hayakawa and Tanaka [16] and also based on the Allcock's formula [31]. The observation of such small dispersion whistlers at Jammu and Bhopal, provides us an indirect and strong evidence in support of non-ducted propagation of night-time whistlers at low latitudes.

Singh and Tantry [32] have made a theoretical retracing study to explain the small dispersion whistlers observed simultaneously at the two stations Gulmarg (geomag. lat., 24°26'N) and Nainital (geomag.lat.,19°02' N) [33] in the realistic ionospheric model. From the ray-tracing studies, they have shown that the VLF waves radiated from the return strokes of the lightning discharge and launched at the ionosphere with different initial wave normal angles, propagated upwards and turned around at different heights and received at Nainital and Gulmarg simultaneously with dispersion of the order of 10 and 15 $s^{1/2}$ respectively. Early, extensive ray-tracing studies by different investigators [16, 34, 35] have indicated that the enhancement factor for the ducts to be able to trap whistlers at low latitudes, is so high (of the order of few hundred percent). Owing to the unrealistically high enhancement factor required, they have shown that the duct propagation seems to be unlikely than non-ducted propagation. Cerisier [26, 27] and Angerami and Carpenter [36] have also found that only non-ducted propagation occurs on lower L-shells. Singh [37] has proposed an interesting nonducted propagation model for nighttime whistlers and have shown that the low latitude VLF waves are propagated to the ground stations in the pro-longitudinal (PL) mode under the influence of negative horizontal density gradients existing in the low latitude ionosphere around the equator. Recently, Ohta *et al* [21] have studied the propagation characteristics of low latitude whistlers by means of the three-dimensional ray-tracing computations for realistic ionosphere/magnetosphere models and explained successfully the high occurrence of echo train (three - hop) whistlers in terms of non-ducted propagation.

The low dispersion night-time whistlers observed at Jammu and Bhopal as shown in Figures (1-4) are non-ducted whistlers and thus consistent with the earlier suggestions of non-ducted propagation mode by different investigators [21, 26, 27, 30, 31, 33-35, 37, 38].

Our results are consistent with the previous work reported at low latitudes (Indian and Japan) [16-19, 21, 34, 39, 40].

5. Conclusions

The detailed spectrum analyses of the whistlers recorded during night time at Jammu and Bhopal, yields the following results.

(i) The morphological characteristics of low latitude night-time whistlers are similar to those of low latitude whistlers reported by various scientists [41-42].

(ii) A large number of night-time whistlers have been observed at Jammu and Bhopal during both quiet and disturbed periods. From the dispersion analysis, it is seen that the dispersion of the whistlers at Jammu and Bhopal are generally found in the range of ~ (3 22 $s^{1/2}$).

(iii) The whistlers are frequently observed during night-times, the rate being higher during mid-night and early-morning hours.

(iv) The whistlers are mostly observed at low latitudes in the month of February to April of the year.

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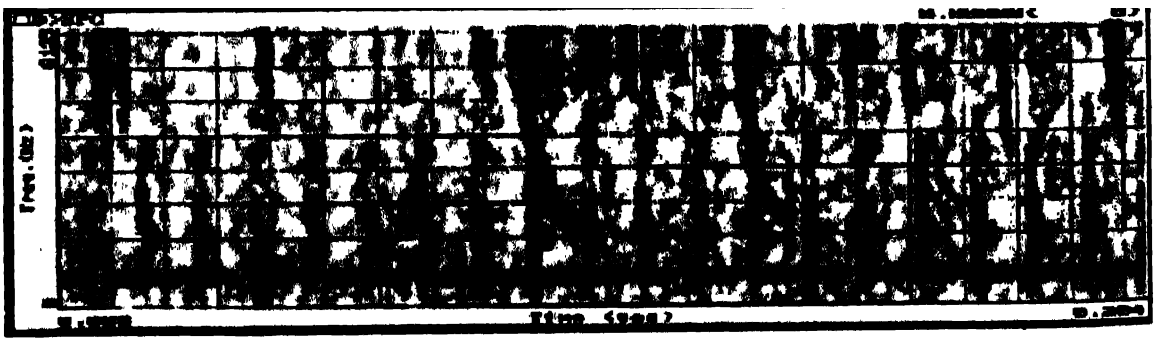

Figure 4. Frequency – time spectrograms of whistlers recorded at low latitude station Bhopal.

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